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HYDRATION AND COGNITIVE PERFORMANCE

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Abstract: A clinical link exists between severe dehydration and cognitive performance. Using rapid and severe water loss induced either by intense exercise and/or heat stress, initial studies suggested there were alterations in short-term memory and cognitive function related to vision, but more recent studies have not all confirmed these data. Some studies argue that water loss is not responsible for the observations made, and studies compensating water losses have failed to prevent the symptoms. Studies in children have suggested that drinking extra water helps cognitive performance, but these data rely on a small number of children. In older adults (mean age around 60) the data are not strong enough to support a relationship between mild dehydration and cognitive function. Data on frail elderly and demented people are lacking. Methodological heterogeneity in these studies are such that the relationship between mild dehydration and cognitive performance cannot be supported.

Key words: Dehydration, cognitive performance.

Introduction

It is of common belief that severe dehydration leads tois associated with a reduction in Cognitive Performance (CP). The rationale is the association of confusion and/or neurological symptoms with acute and severe dehydration, especially in children exposed to fever or high external temperatures, and in frail elderly people during hyperosmolarity or hypernatremia (1). It seems then logical that less severe dehydration should elicit milder symptoms, such as a reduction in CP. If this were so, rehydration, or the prevention of dehydration, or an «optimal» state of hydration should preserve and even increase CP by alleviating the effects of dehydration. A review published in 2005 supported this view (2).

This review will analyse the evidence linking CP with hydration, with a special emphasis on the direct and causative association between these terms. To do this we started from the statement that acute and severe dehydration is associated with confusion and neurological symptoms of a reduction in CP.

The questions posed are: can we affirm that mild dehydration is associated with a reduction in CP ? Are there at-risk populations (frail elderly, children)? Is it the same to relate dehydration to the reduction in CP and to propose that improving hydration prevents cognitive decline or improves CP?

Mild dehydration corresponds to fluid losses by more than 1% of body weight and leads to reduce exercice performance and the ability to control body temperature. Severe dehydration corresponds to fluids deficit of 5% percent or more. It decreases performances and leads to difficulties in concentrate, headache, irritability, sleepness and increases body temperature and respiratory rate. An acute dehydration occurs within hours.

A review was performed in Medline, searching the associations between the terms “cognitive performance” and “dehydration”, followed by a manual search from the literature cited in the articles before july 2011.

Reappraisal of the statement: severe dehydration is associated with confusion and neurologic symptoms

Wilson and Morley have previously reviewed this statement (1). There is a significant risk of a reduction in CP when the brain is exposed to long or acute dehydration. These authors ascribed the symptoms to the hypovolemic reduction of brain perfusion, and to electrolyte and metabolite changes caused by dehydration, such as hypernatremia, or the increased plasma urea concentration (a molecule that easily crosses the cell membrane), or to the alkalosis associated with hypovolemia, or to yet unknown hormonal or metabolic changes. Glucocorticoids and vasopressin may also contribute to memory functions, and cortisol is increased during hydration. Similarly, these authors have suggested that cytokines and nitric oxide may participate in cognitive disorders associated with acute dehydration. Drugs, especially hydrophilic ones, can have adverse effects because dehydration reduces the dilution space. It is therefore proposed that the milieu in which neurons are found (vascular space and glial cells) induces the neurological effects.

Is mild dehydration associated with cognitive impairment?

Table 1 summarises the studies performed before July 2011. It shows that most studies do not find an association between CP and dehydration, particularly when the stress is mild (fluid restriction over a few hours).

There is abundant literature in the military and sports medicine fields that proves the relationship between physical performance and hydration. During an exercise or a competition, the majority of weight loss usually corresponds to water loss. The more the weight comes down the more the performance is impaired. This has been extensively reviewed by Maughan (3) .

The first reports of studies on the relationship between

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Table 1
Systematic analysis of the studies relating cognitive performance and hydration in adults

References	Dehydration intensity (% weight change)	Experimental stress	Change in CP	Tasks affected	Fatigue
Sharma, 1986 (6)	1-3%	Exercise plus thermal	Yes	Memory Complex tasks	
Gopinathan, 1988 (5)	1-4%	Exercise plus thermal	Yes	Memory Complex tasks	
Cian, 2000 (7)	2.8%	Exercise plus thermal	Yes	Memory Complex tasks	Yes
Cian, 2001 (9)	2.8%	Exercise plus thermal	Yes	Short term memory Decision time	Increased by exercise or heat Decreased by rehydration
Neave, 2001 (13)	ND	Water restriction	Unchanged		ND
Ainslie, 2002 (17)	ND	Repeated walks (10 days)	Yes	Decision time	yes
Shirreffs,2004 (14)	2.7%	Water restriction	ND		yes
Szinnai, 2005 (15)	2.6%	Water restriction	Unchanged		yes
Tomporowski, 2007 (11)	ND	Exercise and water restriction	Unchanged		
Patel, 2007 (12)	2.5%	Exercise and water restriction	Yes	Visual memory None of the numerous other tests	yes
Adam, 2008 (18)	2.7%	Exercise in the cold	Unchanged		
D'Ancy, 2009 (10)	ND	Exercise and water restriction	Yes	Reaction time and vigilance attention	ND
Kempton, 2011 (8)	ND	Thermal stress	No	Note a increase in a higher level of neuronal activity	

CP: Cognitive Performance; ND: No data

hydration and CP date from the Second World War, and were conducted by military staff. Granjean et al (4) reviewed these studies, and concluded that there was no evidence of a link between hydration and CP in two thirds of the reports. When an association was found, it involved complex tasks but neither vision nor simple tasks were affected.

The most frequently cited studies relating CP and dehydration combine physical exercise, in a hot and humid environment (thermal stress), with fluid restriction. They were carried out between 1985 and 2000 (5-7; note that two publications come from the same team). Cian et al (7) showed a correlation between thermally and exercise-induced stress and CP. The impaired cognitive functions were short-term memory, tasks combining vision, and motor actions such as tracking a target on a screen. Sharma et al (6) and Gopinathan et al (5), all from the same team, suggested that the cognitive impairment was proportional to the degree of dehydration, with a threshold around 2%. A complete recovery of the impaired function was noted after rehydration, although with marked fatigue. Nevertheless, in a recent study (8), no association was foud between dehydration induced by thermal exercise and CP.

A more comprehensive study was that conducted by Cian et al (9), where volunteers were dehydrated within 2 hours to a target of 2.8% weight loss either by heat stress or by exercise with controls without heat stress or exercise. The tests were also compared following rehydration to restore initial weight. The study had randomised design. Very few tests of CP were impaired, although the battery of tests was quite comprehensive. Similar results were obtained when dehydration was obtained via heat stress or exercise. Short-term memory was the first function to be affected , within 30 minutes after reaching the target weight. It is intriguing to note that memory impairment was observed in both the dehydrated subjects and in those where dehydration was prevented by water consumption. This cognitive impairment disappeared within 3 hours, whether subjects were rehydrated or not. The second cognitive function to be impaired was the time to make a decision during a complex task that involved visual cues. The total number of correct choices was unchanged, but volunteers needed more time to make the correct decisions. Again, rehydration did not prevent the cognitive impairment.

Many studies used exercise in conjunction with water restriction as a means of producing dehydration (10-12). D'Anci et al. (10) observed only mild decreases in CP in healthy young men and women athletes. In these experiments, the only consistent effect of mild dehydration was a significant increase in a subjective mood score, including fatigue, confusion, anger, and vigour. Others studies used dehydration only induced by water restriction (13-15). One study examined how water ingestion affected arousal and CP in young people following a period of 12-h water restriction. While CP was not modified by either water restriction or consumption, water ingestion affected self-reported arousal. Participants reported increased alertness as a function of water intake (13).

To conclude this section: if an impairment in CP can be related to dehydration, it is when the dehydration is mild but acute (a 2% weight loss in a 80 kg man corresponds to about 1.5 litres of total body water lost, i.e. 1 litres intracellular water and 0.5 litre extracellular water). It remains to be proved that dehydration per se (and not other determinants cited in the first paragraph, or fatigue) is responsible for these changes, which are not prevented by rehydration.

Confounding factors in these studies

It is useful to discuss the potential biases in these studies. Because exercise per se stimulates CP (4, 16), all the situations where exercise was associated with another stress have a weakness, especially since the studies involved few subjects. Plasma glucose concentrations may be decreased by exercise and increased by thermal stress (9). In the study by Cian et al (9) a glucose solution was provided to mitigate these changes. However, the changes in the plasma glucose concentrations may reflect more complex changes in the availability of energy- providing substrates to the cells, and this may be a confounding factor.

In almost all the studies reported, young volunteers with intact CP were involved. Moreover, the tests used most of the time in the experiments are simple (memory, association between symbols and numbers, simple video games), although these tests are widely used to address executive functions. It is therefore difficult to imagine that cognitive impairment is easy to demonstrate. Some more complex tests could be used (such as those cited in Cian et al (9)) but with the risk of the findings not corresponding to real-life situations. Another possibility would be to use simple and robust tests in more frail populations, in whom CP may be impaired and more sensitive to constraints. It is noticeable that in Kempton‘s study (8), no changes in CP were observed but an increase in the brain perfusion was demonstrated (measured by functional MRI) suggesting that CP may have been maintained at the expense of an increase in blood flow. It is certainly a hypothesis to study, although as yet there is little evidence to support it.

It should also be acknowledged that the number of volunteers in each study is small (6-10, 13-17), and these trials may not have been appropriate to test the hypotheses. Each subject was often his/her own control, and it raises the question of the learning or the training with the tests (if a repeated design is chosen). The internal precision and repeatability of the tests is also an issue.

The prevalence of fatigue is also worth considering. It is therefore difficult to say that it is dehydration per se that is responsible for the CP changes observed, and it raises a possible explanation for the lack of efficacy of rehydration. Most of the studies are performed on military personnel to evaluate soldiers' ability to function in extreme circumstances. It is easy to imagine that a soldier fighting in the desert with a heavy rucksack and a protective suit must be physically and cognitively at his best. It is, however, very difficult to translate this knowledge to normal real-life circumstances. Moreover, with different stress conditions (exercise in the cold) Adam et al (18) suggested that dehydration was not responsible for the observed changes.

Weight changes are usually used to evaluate hydration status and water losses, which is most of time adequate taking into account the short duration of the experiments (2 hours). However, it is not known whether water lost is intracellular or extracellular, or a mixture of both. When intracellular water is decreased, cell function may be impaired. If extracellular water is lost, then indirect mechanisms, such as perfusion flow or the transparency of the aqueous milieu (E.G. in eye lenses) will mainly affect specific cells such as those in the retina. The lack of an intracellular indicator is clearly a handicap in the evaluation of the mechanisms behind the changes. Numerous studies have used measure of total body water by bioelectrical impedance monitor (19-21). Bioelectrical impedance has been extensively validated as a measure of hydration status and found to be a highly reliable instrument. In 2 studies (19, 20), authors studied the relationship of the ratio of total body water to weight on CP. It is of note that the ratio of total body water to weight is a poor indicator of cellular hydration as the ratio tends to decrease as weight (and fat mass) increases (such as in obesity). This illustrates the complexity of the relationship between dehydration and CP.

Are there populations at increased risk of Cognitive impairment?

In this section we will focus on CP changes associated with dehydration in the elderly, the frail elderly, and children. The rationale for this question is that if CP changes are difficult to demonstrate because volunteers are young and cognitively fit, any changes may be easier to demonstrate in frail people.

In elderly people, only a few studies are available. One by Suhr et al (19) studied the relationship of the ratio of total body water to weight on CP in 28 healthy persons (22 women) with a mean age of 63 (ranging between 50 to 82). The authors showed an inverse relationship between the ratio and memory or the speed to complete the tests. A multivariate analysis (because age negatively influenced the CP) suggests that 17 to 20% of the variance is explained by the ratio between total body water and weight, with limit cited above. The same authors (20) replicated a similar study on middle-aged women and showed that the negative effect of the ratio between total body water and weight on memory was mediated by an increase in blood pressure that explained most of the effects.

A second study carried out by Ainslie et al (17) analysed the changes in total body water (evaluated with morning urine osmolality) on CP after a 10*10 h walk (about 20 km with a 1200 m change in altitude, repeated each day for 10 days) in 10 subjects aged between 51 and 60. The authors concluded that the higher the osmolality the slower the answers to the tests. Finally, Ackland et al (21) analysed the influence of the preparation for a colonoscopy in 38 patients (mean age 60), who were otherwise healthy. The preparation induced a 2% body weight decrease, i.e. a 2.6% decrease in total body water. The study did not show any change in tests of attention, memory or more complex tests. No studies have been carried out on older old subjects or frail elderly subjects. Patients suffering from Alzheimer's disease, in whom the cognitive decline is a critical issue for autonomy, have not been the subjects of study on the relationship between hydration and CP, although patients with more severe cognitive decline appeared malnourished and dehydrated (22). The same is true for malnourished people with low weight (hence a small water reserve) and a reduced food intake (hence a reduction in water intake).

Children are a second population of interest. Body surface area is greater per unit of body weight in children than in adults, and they have a lower body water volume. Therefore, water loss is more likely and the water reserve is smaller, making children more prone to dehydration, especially under heat stress. It would be unethical to submit children to the same dehydration constraints as those imposed on adults. Bar-David et al (23) have analysed the CP in 2 groups of children living in the hot southern regions of Israel classified according to urine osmolality. The children with the highest osmolality (higher than 800 mosm/kg) had lower memory performances, a tendency for a lower semantic flexibility (the capacity to associate words that sound similar), and a reduced capacity to differentiate similar figures. Their mathematical capacity was not affected.

Edmonds et al (24) studied 58 children with a mean age of age 8. Half of the children were encouraged to drink as much as possible during the 20 minutes before the CP tests (they drank a mean of 212 ml). The other half did not drink. The children who drank (although perceiving the same thirst) had better results on a test involving vision (finding a hidden symbol within a grid, and finding differences between almost similar pictures) but did no better in tests that involved motility and vision (draw a curve between dots) or in memory tests. The same team has reproduced the experiment in 23 7-year old children, who consumed 409 ml (25). This experiment confirmed the results from the first publication. However, in research described by Benton and Burgess (26), memory performance in the same children was improved by the provision of water but sustained attention was not altered.

Conclusion

Can we affirm that mild dehydration is associated with a reduction in CP? Are there at-risk populations (frail elderly, children)? Is it the same to relate dehydration to the reduction in CP and to propose that improving hydration prevents cognitive decline or improves CP?

An association between severe and acute dehydration and cognitive impairment (coma, confusion, focal neurological symptoms, or sequelae after a mismanagement of rehydration) was described in early studies. However, the most recent literature tends to refute this relationship. Very few studies addressed the relationship of mild dehydration and CP, the evidence is not certain that rehydration or the prevention of dehydration during the same hydration stress prevents the reduction in CP. In a high dehydration risk population, it seems that the increase in fluid consumption improves CP. However, these studies are sparse and involve a small number subjects to support a relationship between mild dehydration and CP is weak and there is no data for frail persons.

A number of methodological difficulties and biases prevail in the published studies. Studies must be powered to the outcome with an accurate definition of the primary outcomes integrating precision in the measurement of CP. The choice of the population to be studied is strategic, and it is probably unwise to expect massive changes in CP in young subjects with high physiological and cognitive fitness. A careful choice of the CP tests is warranted, in order to compare results between age groups and/or between populations.

It is therefore uncertain to conclude that there is or there is not a relationship between mild dehydration and CP. Because this is a strategic issue with potential nutritional allegations it is necessary to implement high quality studies using appropriate methodology to obtain accurate answers. An approach similar to that of clinical trials is needed with a dose-response relationship approach.

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